

SHARPNESS AND NOISE IN DIGITAL CHEST RADIOGRAPHS, ASSESSED BY VISUAL RATING

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Abstract

Missed lung lesions are one of the most frequent causes of malpractice issues, caused by several reasons; among them suboptimal radiography. When radiographers interpret acquired images of a patient, an acceptance or rejection must be decided. When a retake is required, radiographers need to know how to improve the image quality. Improvements in image quality properties as contrast, sharpness and noise often lead to improved perception, which in turn should enable more information to the observer and also allow computer-assisted detection (CAD) to be more successful.

Our aim was to create a scoring system of the principal limiting factors sharpness and noise, in a clinical setting, and to determine whether it is possible to agree on image quality on digital chest radiographs. To enable a variation in rating due to body habits, a three-graded scale for each of sharpness and noise were created. Five different anatomical landmarks in each of patients having body sizes lean, normal and large were evaluated by 27 radiographers; totally 810 scores were given.

The results showed a high inter-observer agreement with respect to rating grades of both sharpness and noise, independent of projection, anatomical landmark and body habits. The present study is a first step in the development of a scale for assessing sharpness and noise in digital chest radiography. The method of quality assessment might become more valid with increased use. We propose that this study can be followed up by a systematic mentor-guided training program that links perception of image quality to feedback about the image retake decisions if required.

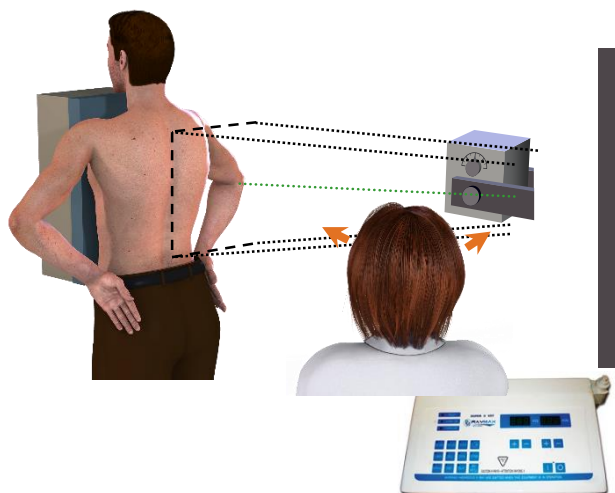
Keywords: Digital imaging, exposure techniques, image acquiring, image quality, optimization, radiographic interpretation

Introduction

Chest radiography is one of the commonest radiographic examinations performed, used as the primary examination for a range of clinical situations, including lung cancer. Lung cancer remains the most common malignancy in the world. Far more men than women still die from lung cancer each year, but the gender gap in lung cancer mortality is steadily narrowing and will eventually close (Medina & Blackmore, 2008). Global lung cancer incidence has followed the trends in smoking with a lag time of several decades. The present pandemic of lung cancer followed the introduction of manufactured cigarettes with addictive properties, which resulted in a new pattern of sustained exposure of the lung to inhaled carcinogens. Given the large population of adult cigarette smokers and former smokers worldwide, there is a large population at risk for lung cancer. Most patients who receive a diagnosis of lung cancer have advanced stage disease, making curative treatment unlikely. With an early stage disease, however, individuals can achieve cure through surgical resection (Bach, 2003). Highest image quality of chest radiographs are therefore of importance.

The importance of high-quality radiography

The framework for the efficacy of diagnostic imaging procedures, a 6-tiered hierarchic model (Fryback and Thornbury, 1991) includes levels from the most concrete to the most controversial; technical quality, diagnostic accuracy, diagnostic thinking, therapeutic decisions, patient outcomes and societal perspectives. The technical efficacy, level 1, concerns technical quality of the equipment. Level 2 addresses diagnostic accuracy, sensitivity, and specificity associated with interpretation of the images; highly dependent on the radiographer's ability to produce high-quality images by use of proper positioning, optimal exposure factors related to the habit grade of the patient, and an efficient cooperation with the patient for acquiring the best signal-noise ratio information for further optimal post-processing (Figure 1). Given the serious implications for the patient as for the society; quality scaling and improvement of acquiring optimal chest images are sparsely focused.



Figur 1: The ability of the radiographer to produce high quality images relies upon the combination of proper positioning, optimal exposure factors chosen related to the habit grade of the patient, an efficient cooperation with the patient to ensure a deepest respiration breath-hold; which should acquire a high signal-noise ratio information for optimal post-processing.

Errors in film-screen chest radiography

Studies on errors in detection began to be reported in the academic press in the mid-1940s (Garland, 1959). Several papers were based on second reading of films, usually chest films.

Errors, inevitably, are of three categories; a false positive diagnosis caused by misinterpretation of a structure/ nodule as lung cancer; a false negative diagnosis caused by incorrect interpretation of lung lesion as benign; and the failure to recognize a cancer. Generally, false-negative errors are stated to be five times more common than false-positive errors(European Society of Radiology; 2007). The former are correctable with training and the latter partly correctable with training and experience(Garland, 1959).

A reason for false negatives is suboptimal images, as too often being produce(Monnier-Cholley, 2005; European Society of Radiology, 2007). Missed lung cancers on chest radiographs have been a frequent cause of missed diagnosis over a range of years(Garland, 1959; Turkington, 2007; Quekel 1999). A false negative diagnose incurs a high cost for the patient with delay in diagnosis and treatment of the disease. In a study of overlooked lung nodules, conducted by Quekel (1999) the median delay in diagnosis was 472 days. The survival time for the patient was significantly shortened.

The exact missing rate in the detection of early lung cancer of chest radiography is difficult to estimate. The missing rate in the primary reading of radiographs was reported to vary from ten to 30% in the foremost study by Garland in 1959 while others reported a variation of 20-50%(Forrest and Friedman,1981). Moreover, Quekel et al(1999) highlighted the problem by reporting even up to 90% errors, though; the design of the studies varied. It is notable that image quality was considered perfect in only a few cases among images with ignored cancers(Monnier-Cholley, 2005).

Common signs of lung cancer in chest images, although non-specific, are described elsewhere. It is generally stated, that the larger the nodule the higher the probability of malignancy (Lazaroti and Boulikas, 2008). In a retrospective study of prior radiographs, nearly 90% of the nodules were visible(Muhm, 1993). Similarly, tumour sizes ignored estimated retrospectively, varied between 10-70mm(Monnier-Cholley, 2005) , 8-70mm (Muhm, 1983), 0.6-34mm(Austin *et al*, 1992), 6-45mm(Sone, 2000) and 10-32mm(Shah *et al*, 2003).

Lung cancers might be located at any place within the chest including the peripheral area in the lungs. Nedumaran et al(2004) found the cancers being 90% centrally located, while Quekel et al(1999) found failures were not dependent on location. On the other hand, superimposing structures can mask a lesion; e.g. when scapula is over-projecting lung tissue. Proper positioning is a necessity when 26% of the lung volume may be concealed by the thoracic spine, mediastinum, heart and diaphragm on a PA projected image(Chotas,1994). In the study of Nedumaran et al(2004), 2/3rd of the false negatives were superimposed of other structures; e.g. when scapula over-projects lung tissue and masks a lesion.

Adenocarcinomas, which frequency increases, occur typically at the periphery of the lung, and, as a result are often asymptomatic until late in their course. In the previous studies the frequency of adenocarcinomas were 31% (Monnier-Cholley, 2005), 24% (Muhm, 1983), 33% (Austin, 1992), 91%, (Sone, 2002) and 45% (Shah, 2003), respectively. Detection failures were strongly related to the blur of the edges of pulmonary nodules. Quekel (1999) revealed that lesions' detection probability could be from almost 90% sharply bordered to 30% unsharply bordered. Austin et al

(1992) stated that 95% of the missed lesions were unsharp bordered. In Queckel's study (1999), 73% of the missed lesions were partly or totally unsharp bordered.

Errors in digital chest radiography

Digital Radiography (DR) was introduced with a hope that the accuracy should increase. On digital radiography and CAD, Berlin cited in 2007 (Berlin,2007):

Digital technology can potentially improve screening by providing compatibility for computer-assisted detection of lesions and by permitting flexible manipulation of grey-scale and edge enhancement of the images presented to the radiologist.

Whether digital radiography and CAD will once and for all substantially reduce radiological error, nevertheless, the rate of which has not been changed during the nearly half century since Garland's classic article from 1959 appeared (Garland,1959), is yet to be determined. Berlin (2007) further cites:

Technology doesn't solve, but only displaces, the problem of perceptual error to a new and different technology, offering the opportunity to make a whole new, and maybe longer, list of mistakes. You can't buy excellence in a box, although you can keep buying newer and more expensive boxes.

Chest retake rates are reduced with DR due to its increased latitude; but exposure problems still lead to 52% of the retakes in a subgroup analysis among Computed Radiography (CR) (Polunin, 1998). However, Wu et al (2008), found that retakes with CR were similar to conventional film-screen techniques; tumours ignored were sized 10–32mm, and 63% of the tumours were carcinomas.

A reject analysis of 288.000 CR image records was published by Foos *et al*, 2009. Of these images collected from two large hospitals whereas chest exams were the most frequently performed examination at both institutions; positioning errors and anatomy cut-offs, followed by improper exposure were reasons for the most frequently occurring overall rejects. "Patient motion" was manifested as a reason for rejection, but the reason for this was often poor positioning. This, in turn, caused the image processing algorithms to render the images with lower than desired average density, resulting in an image as being underexposed even having normal Exposure Index (EI) values. Using visual interpretation, these images were found to have excessive noise appearance; however, the appearance was not graded. Overexposures counteract visualising noise. Noise could also remain in the image due to a lack of noise reduction in the CR plate reader. Foos *et al* (2009) highlighted the feedback from rejecting images to ensure better acquiring.

In a study of detection of missed lung cancers, the authors reported that even though the use of full range of PACS tools as windowing, leveling, magnification, gray-scale manipulation, lesions were overlooked; thereby CAD was reported having a potential to detect approximately half of the lesions overlooked by human readers at chest radiography (White,2009). Still, using new expensive tools, a large number of lesions are left being undetected.

To assure reliable performance and reproducible results from a digital radiographic system, the system needs to be properly installed, maintained, and monitored through a quality control program. For the technical equipment and monitors, routine quality assurance (QA) tests are developed (Institute of Physics and Engineering in Medicine, 2005). For the workflow paradigm of digital radiography, it is stated that QA is a “missing link” while the radiographers despite the inroad of the digital revolution typically replicate the screen-film paradigm (Reiner *et al*, 2006). According to the efficacy model of imaging (Fryback and Thornbury, 1991), the ability of the radiographer to evaluate the acquired radiograph is also imperative. Without this ability, the attempt to attain quality is futile. After the exposure of a patient, the acquired image is displayed on the radiographer’s workstation for interpretation of correct patient identification, proper positioning and exposure techniques, as well as artefacts, prior to image processing. It is the radiographer’s task to decide if an exposure must be repeated, or not.

A radiographer should do a sensible systematic image interpretation, impacting both doses and image quality of each one acquired image (Figure 2) both before and after post-processing, before storing into the Picture Archiving and Communication System (PACS).

A graded scale of performance might give a directional help if a repeated exposure is needed, when the reasons for failures are identified, for to correct the steps that can give a more satisfactory radiograph.

A radiographic quality assessment (RgQA) method hereby created and tested, using visual grading as an assumption that the possibility to detect abnormal findings correlates to the reproducibility of normal structures; and also visual grading of the texture in an image.

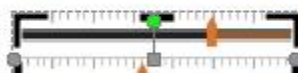


Figure 2: Interpreting image quality before post-processing is visual check on positioning, markers, artefacts, pathology, and exposure techniques, compared to doses used. Using the RgQA method, it includes visual grading correlated to the reproducibility of normal structures on certain structures and also visual grading of the texture in the image, measured on a standardized basis. A gradual scale is more effective than the yes or no-basis. Image perceptions can feedback image retake and optimization decision.

Guidelines

Guidelines for film-screen are well known (European Guidelines, 1996). For digital radiography, explicit guidelines are still vague. A proposed guideline from DIMOND (2009) does not give sufficient help for radiographers to ensure if the acquired image is adequate. Quality evaluation of images are based on radiographers’ subjective scoring because of lack of objective and acknowledged criteria. High technical quality properties of chest images are high sharpness, low noise and high contrast (Vyborny, 2003). By post-processing, contrast is easily changed, except for saturation. The principal limiting factors for image quality in DR are sharpness and noise (Vano 1995; Kroft 2005); what properties mainly are dependent on the image acquiring. Noise can be

reduced by post-processing, but with the cost of loss in sharpness. The ability to do a proper post-processing lies onto a qualified acquiring of image data.

Mammography has led the evolution of quality assessment (QA) in radiography. Mainly, the technical image quality criteria are focused, e.g for the “Radiologic Technologist Quality Control Forms” (American College of Radiology, year unknown). Clinical image quality for film-screen mammography developed the PGMI model (Hofvind, 2009). However, Taplin (2002) studied clinical image quality and added impression on attributes, among others, and also graded them, for positioning, compression, exposure, sharpness, noise, artefacts, and contrast.

Image details

Image detail features is a combination of spatial resolution and contrast resolution. Spatial resolution is achievable using physical measuring techniques. Resolution is the physically measured parameter that refers to the minimum resolvable separation between high-contrast objects (Carrino, 2002), thus sharpness as an image criterion is considered as the perceptual distinctiveness of outlines and edges. Interpretation sought to evaluate the feature of an edge or the ability to display density boundaries in an image, to evaluate details such as small objects or separation of objects.

Contrast resolution is the ability to distinguish between differences in intensity in an image (Sprawls, 2005). In medical imaging, contrast resolution (or contrast-detail) is used to quantify the quality of acquired images. It is a difficult quantity to define, because it depends on the human observer as much as the quality of the actual image. The physically measured parameters thus, are the contrast-to-noise ratio, which often is employed as an index for contrast because this metric does not require a reference signal. Image contrast is, in addition to x-ray penetration characteristics, significantly affected by scattered radiation and the contrast characteristics of the receptor and display system.

All imaging processes are degraded by noise and blur. Noise, also called mottle or graininess, is superposition of a meaningless set of signals over meaningful signals.

Noise, as an image criterion is considered as the perceptual distinctiveness of information that does not have a meaning. Noise as a physically measured parameter that refers to random variation in grey-scale presentation that unwanted interfere with the detection of the ‘true’ signal that is sought (Carrino, 2002). Two primary factors contribute to noise; quantum noise are photons that arise from the discrete nature of electromagnetic radiation and its interactions with matter, while as electronically noise arises in detectors and amplifiers in the imaging system. To make it clearer; radiation noise is information in the beam that does not contribute to the image, such as scattered radiation. Anatomical noise refers to information about structures in the area of interest that does not contribute to the usefulness of an image, as superimposing structures. All fluctuating intensities present on an image are unsharp random distributed backgrounds, visualized as a “salt-and-pepper” texture. Noise is inversely correlated to the dose. For digital radiography, higher doses result in less noise, i.e. better image quality, in a certain range of dose.

Too high dose is a risk in DR, and can be used without an adverse impact on the image quality, while underexposure usually becomes evident because of deterioration of image quality by increasing quantum mottle (Vano, 2005). Dose creeping is a serious problem. Seeing large objects depends on structure, while seeing small objects depends on quantum noise (Marshall *et al*, 2003). In this way, noise can be used as a direct measure of image quality in optimizing patient dose (Doyle, 2005). Visibility of image noise can often be reduced by blurring, that tends to blend each image point with its surrounding area; the effect is to smooth out the random structure of the noise and make it less visible (Sprawls, 2005). Blurring reduce the visibility of useful image details. Image quality is much more sensitive to noise compared to blur, although a trade-off relationship exists between noises and blur.

Radiographic unsharpness consists of a mixture, based on geometrical features (focal spot size or magnification) and blur. Clinical structures of interest in a patient are placed in different localizations between the focus and the receptor, and they will thereby be represented on the image with different grades of divergence. These presentations interfere also with at what quality the information are acquired on the CR or DR system used (based on technical properties, exposure techniques, pre- and post-processing algorithms used), and latter presented visually on the monitor. Among sources of sharpness, movement degrades quality the most. This is imperative dependent on the cooperation between the radiographer and the patient; in chest radiography affected primarily by the breath-holding process.

Radiographic quality assurance

Undertaking a systematic *radiographic* quality assessment (RgQA), the evaluation of anatomical landmarks and texture within an image, that influence and guide the strategies for decision-making on retake, have not previously been addressed for digital chest radiography. RgQA could hopefully generate awareness by creating knowledge about reasons for retakes, and also help understand how image-acquiring process is connected to image quality.

The aim of this study was to create a scoring system of the principal limiting factors sharpness and noise, in a clinical setting, and to determine whether it is possible to agree on image quality on digital chest radiographs.

Methods and materials

Thirty radiographers, actively involved in routine chest radiography, were invited to take part in the study for grading of sharpness and noise. Twenty-seven (90%) of them volunteered to participate.

Images

Anonymized chest images of three patients consisted of posterior-anterior (PA) and left lateral (LAT) projections, chosen independently of the clinical problem. The images were without

obvious pathology. They had been taken within a random two-day period, using same equipment; Direct Ray (Hologic's Direct Radiography Corp. Newark, Del), a large-area flat-panel detector, employing amorphous selenium as an X-ray converter material. The software version was DR 1000, using Direct Ray Operator Console Version 1.6 and Array Controller Version 3.3.04 (Del Medical Imaging Corporation, 2003). PA and LAT projections were made using 125 kVp, 1.7mm Al filtration, a fixed focus size, fixed source-to-image distances, and the automatic exposure control. Images were post-processed with the same look-up table before data were transferred to PACS. Images evaluated were stored in the hospital's PACS; Kodak Direct View PAC system 5, version 2 (Eastman Kodak Co., Rochester, N.Y.). Images used for this study were considered as '*suitable quality for diagnostic use*' as they already had been used for reporting. Dose measurements were not available.

We sought the broadest possible variation in body habit to provide high discrimination between the properties of sharpness and noise. None images of obese patients were found. The images that were chosen represented one lean patient (patient 1), one normal-sized (patient 2), and one over-weight patient (patient 3). Of the patients, two were females and one was male with the respective age of 24 years(y), 64y and 43y. Their bodies' size were classified according to the diameters in their equal-sized images; PA projections at the outer contour of the costae and at the height of carina, as 23.7, 26.4 and 30.4 cm respectively; and LAT at the outer margin of the skin, at the height of carina, as 21.3cm, 31.5cm, and outside the exposed area for the largest sized patient (>31.5 cm), respectively. The size of the exposed area was chosen according the size of the individual patient.

Anatomical landmarks

Anatomical landmarks the RgQA method were chosen as easy replicable; three in the PA-projected images and two in the LAT-projected images. Ensuring multiple landmarks were preferable since chest pathology might appear almost anywhere in images. Each radiographer was provided an arrowed illustration of the anatomical landmarks (**Figure 3 a and b**) to facilitate the readers to score exactly on the equal locations.

The reasons for choosing the appropriate anatomical landmarks were several; the structure types (Vynorny, 2003; Fink *et al*, 2002; Vyborny, 1997), the movement of structures (De Groote *et al*, 1997), the target types (Vyborny, 1997), as well as the scatter to primary ratio (Håkansson *et al*, 2007). These factors, listed in Table 1, do to some degree interact. The situation of point targets is of particular interest for pneumoconiosis. Another quality rating should probably be created for clinical question of point target types, as this might imply another set-up of the system. The convolution kernel size in the pre-processing algorithm is than of great importance as it promotes noise suppression. This would assume another RgQA rating than the target types typical for lung cancer, the lines targets and nodules targets; therefore point targets were excluded for this RgQA model.

		Posterior-Anterior projection			Lateral projection	
		Outer third of right side lung	Contour edge of right side diaphragm	Heart contour	Retro cardiac area	Lung and columna over projected at the height of carina
Structure type	Lung structure	1	0	0	2	1
	Soft tissue	0	1	2	1	0
	Bone	0	0	0	0	1
Movement		2	2	2	2	2
Target geometry	Lines	2	1	1	2	2
	Nodules	2	2	1	2	2
Signal to noise ratio	High	0	2	1	2	2
	Medium /low	1	0	0	0	0

Table 1: Causes of variation in properties that influence on sharpness and noise, were graded in five localizations in a set of chest radiographs; three in the PA-projection and two in the LAT-projection. Rank 2 is assumed to indicate a greater importance than rank 1, while as rank 0 assumes being of no interest. Point targets are not included in target geometry (see the text). Sources of sharpness deterioration, visualized as less prominent edges, are patient movement, tissue (organ or structure) movement, or equipment movement. Sources of noise deterioration, visualized as the "salt-and-pepper" texture, are the variation of radiation and its interactions with matter, electronically variation of noise in detectors and amplifiers, scattered radiation, and superimposing structures. To some degree, they interact.

Construction of grading scales

In planning of this study, it was noted that sharpness was evaluated subjectively by the impression of anatomical structures, while noise could be evaluated by the combination of the impression of anatomical structures and the generic (textural) feature observed. A grading scale were created on the basis of anatomical and generic features based on the experience from digital mammography using dichotomized grades (van Ongeval *et al*, 2008) and analogue mammography using a five-graded scale (Taplin, 2002). This five-graded scale created for mammography was later collapsed into three grades, as the respective ratings had been concentrated mainly only three grades. Thus, a three-graded scale for sharpness and noise, respectively, were constructed for this study, as shown in Table 2.

For sharpness, the scoring criteria alternatives were optimal, medium, and poor; and for noise the criteria were minimal, moderate, and high; where the score 'high' represented minimal noise grade as the most sought after.

Image evaluation

Radiographers were provided written instructions containing information needed to avoid inconsistencies regarding the performance of the tasks. The landmarks for evaluation are shown in Figure 3 a and b. Radiographers do the image interpretation at the modality's monitor. In this case, panellists were asked to evaluate the images using the identical *diagnostic* high-quality monitor. Illumination in the reading room was as normally used for image interpretation and reporting, and was not remarkably different from the illumination with the *radiographic* modality's monitor, as confirmed by the radiographers.

Radiographers were allowed to view images in groups, however they were asked to score individually. All participants were forced to provide their ratings, even though some were uncertain when. During the planning of this study, it was noted that radiographers seldom used magnification; they rather preferred windowing for viewing images. For the RgQA rating, no restrictions were applied regarding the use of window/level, pan or zoom functions, or differing with viewing distance.

Sharpness was graded subjectively using the following three grades:
1 = Optimal sharpness. When important structures are seen optimal in the image.
2 = Medium sharpness. When important structures are seen.
3 = Poor sharpness. When important structures are poorly seen or not seen and these are in such a manner that the structures in the patient are hardly to evaluate.

Noise was graded subjectively using the following three grades:
1 = Minimal graininess. Almost no 'salt and pepper-structure' is seen.
2 = Moderate graininess. Some 'salt and pepper-structure' is seen, but the structures of the patient can be evaluated.
3 = High or severe graininess. With "salt and pepper-structure' easy seen, in such an amount that it reduces the visualisation of structures in the patient, or the noise can give a false impression of structures in the patient.

Table 2: scales for sharpness and noise

Data analysis

An analysis of inter-observer agreement was required desired to assess the objectivity and reliability of the subjective image evaluation. Thus, observer scores were ordinal data. Frequencies and summary information were calculated using SPSS version 17. P-value <0.05 (two-sided) was regarded to be statistically significant.

Ethics

The study was considered ethical by the head of Department of Radiology, Drammen hospital. The study was used as part of quality improvement.

Results

Sharpness and noise in all five anatomical landmarks of the three patients' images were evaluated by 27 radiographers, producing 810 scores. All radiographers used all three steps in the rating scale when scoring (not shown in tables). The distribution of sharpness and noise grade assessment is shown in Table 3, and illustrated in **Figure 4 a and b**.

A distribution representing random choice would be close to 9 in each category. Score frequency range was 0/27- 20/27; thereby the maximal frequency was 74%, given for a medium grade.

A high inter-observer agreement with respect to scoring of both sharpness and noise was observed. Of 30 evaluations, 28 showed a score distribution with a statistically significant difference from random distribution (Table 3).

The medium score was most often chosen for both sharpness and noise for all anatomical localizations in both projections, for all three

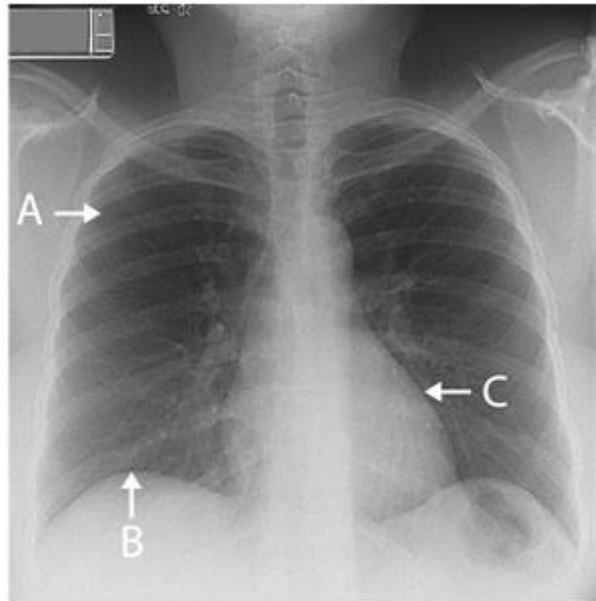


Figure 3a: Landmarks for evaluation of sharpness and noise are indicated by arrows. In this PA projection showing: A) Peripheral vessels at the outset one third of the patient's right lung without superimposing by costae or scapula. B) The retro cardiac vessels in the dark angle area posterior of the heart. C) Lung structures superimposing bone structures upon the thoracic column, at height of carina.

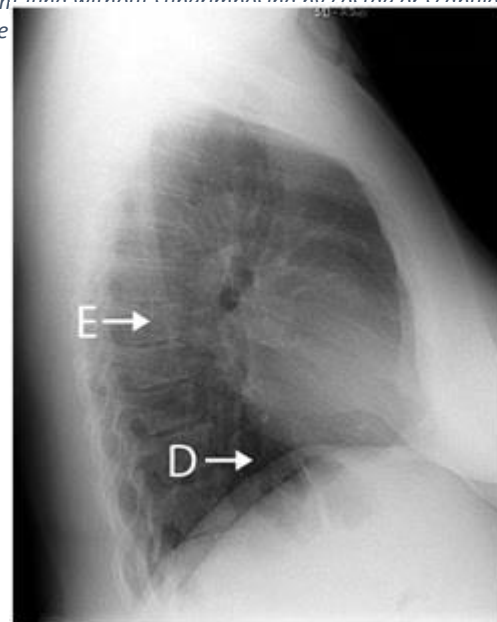


Figure 3b: Landmarks for evaluation of sharpness and noise are indicated by arrows. In this lateral projection showing: D) Retro cardiac vessels/the retro cardiac area (the "dark angle area" posterior of the heart) E) Lung structures superimposing bone structures upon the thoracic column, at height of carina.

body sizes. The medium score was given in 51% of the images evaluated for sharpness, and 52% for noise.

Projection	Localization*	Sharpness grades**	Sharpness grades**						Noise grades**						
			Lean patient	p-values†	Normal sized patient	p-values†	Over-weight patient	p-values†	Lean patient	p-values†	Normal sized	p-values†	Over-weight patient	p-values†	
PA	Lung parenchyma outer 1/3	Optimal	9	0.02	3	0.03	5	0.17	Minimal	11	0.01	1	0.004	11	0.01
		Medium	15		14		13		Moderate	14		14		14	
		Poor	3		10		9		High	2		12		2	
	Diaphragm contour	Optimal	15	0.003	1	0.005	9	0.004	Minimal	16	0.002	0	0.003	2	0.000
		Medium	12		13		16		Moderate	11		12		19	
		Poor	0		13		2		High	0		15		6	
	Heart contour	Optimal	9	0.001	3	0.003	13	0.045	Minimal	9	0.4	0	0.000	3	0.001
		Medium	18		7		11		Moderate	12		8		18	
		Poor	0		17		3		High	6		19		6	
LAT	Retro cardiac area	Optimal	13	0.005	5	0.01	4	0.000	Minimal	11	0.01	11	0.01	0	0.000
		Medium	13		8		19		Moderate	14		14		19	
		Poor	1		14		4		High	2		2		8	
	Lung structures over projected column at carina height	Optimal	5	0.000	5		3	0.03	Minimal	8	0.03	0	0.004	0	0.002
		Medium	20		15		14		Moderate	15		15		11	
		Poor	2		7	0.045	10		High	4		12		16	

Table 3: The lean patient is patient 1, the normal sized patient is patient 2, and the over-weight patient is patient 3 in the text. *Localizations or rating of sharpness and noise, see Figure 3a and 3b. **Definitions of sharpness and noise grades see table 2. † Chi-square tests (two-sided) for deviation from random distribution, p < 0.05

The poorest sharpness score and the highest noise grades represent the worst quality rating in these scales. For all anatomical localizations in both projections for the medium-sized patient lowest quality were rated by 58% and 54% (61 and 60 scores) respectively; illustrating there are a common understanding of a potential for better quality. This was for the normal-sized patient (patient 2). The ratings were given quite similar for the PA and the LAT projected images.

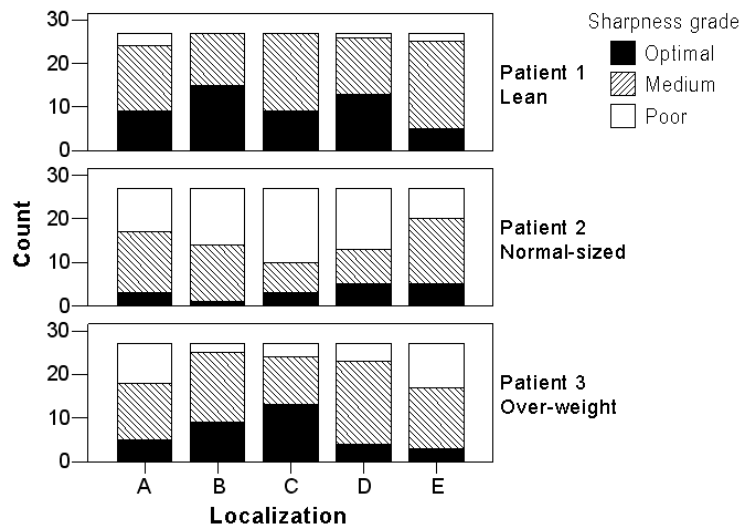


Figure 4(a)

When sharpness score values were summed for all five localizations, the lean patient's (patient 1) images was rated as 51 occasions and poor in 6 occasions. Likewise, the overweight patient's images (patient 3) were rated optimal in 34 occasions and poor by 28 occasions. This indicates the qualities in the lean patient's images (patient 1) were rated as prior to the over-weight patient's images (patient 3).

Discussion

In this study, using a psychophysical approach, we have designed and tested subjective assessment of sharpness and noise in a clinical setting. The results are based on observer's preference rather than diagnostic performance making them relevant for the radiographers' role in the imaging procedure (Båth, 2007). The number of images was few, as this study represents the very first steps in developing a subjective scale for radiographic evaluation of the image properties; namely sharpness and noise.

In the 65 years since radiologic errors were first acknowledged, the error rates have not decreased appreciably. In general, the number of retakes of images has decreased after the introduction of digital radiography; as visual characteristics can be

significantly improved by adjusting the intensity in areas of different radiation absorption, and also by using different algorithms for reducing noise. Furthermore, the characteristics of the displayed image will also be influenced by the transfer characteristics of the display system used for presentation. However, this retakes alone may not indicate overall improved image quality and optimal radiation dose. An acceptable level of contrast and brightness can be obtained through post-processing, even with a noisy image (Foos *et al*, 2009). It has been proposed that the two biggest quality errors in computed radiography (CR) are related to poor positioning and noisy images. This is probably just as relevant for digital radiography (DR). Quality assurance with DR is regarded as even more important than with CR (European Commission, 1996; Verschakelen, 2003). Consequently, better quality assurance measures are needed. In a study of analogue mammography, detection of interval cancers was found to be related to suboptimal image quality (Taplin, 2002). In particular, failures in positioning, followed by sharpness and noise, were shown to be of importance for the detection. Mammography has been a model on the development of QA in imaging, also for RgQA, however it still lacks a specific RgQA method for digital mammography. The RgQA method for analogue mammography, the PGMI, showed in a Norwegian study that it still is a challenge according to the inter-observer agreement (Hofvind, 2008). With precisely terminology, even subjective scoring can be good, as tested by inter-observer variability among radiologists in mammography (Lazarus *et al*, 2006).

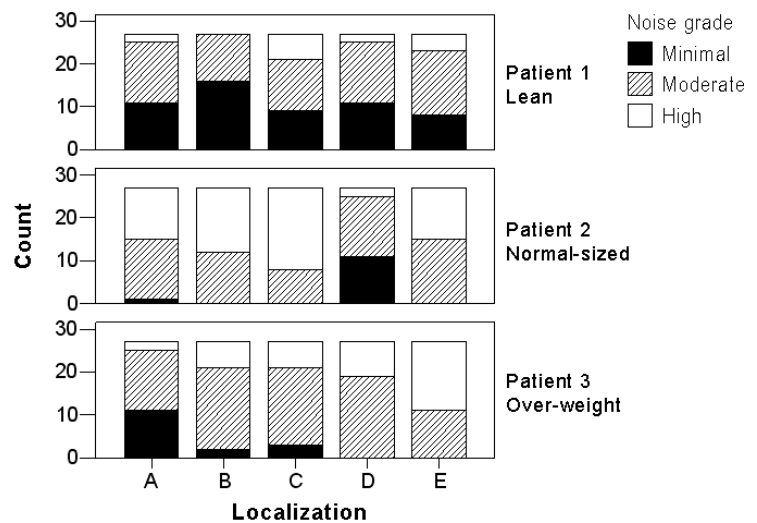


Figure 4(b): The distribution of sharpness grades*(a) and noise grades grades*(b) assessments in different localizations** in posterior-anterior (A-C) and lateral chest projections (E-F). A) Peripheral vessels at the outer third of the patient's right lung without superimposing costae or scapula. B) The contour of right side diaphragm. C) The heart contour. D) Retro cardiac vessels/the retro cardiac area (the "dark angle area" posterior of the heart). E) Lung structures and bone structures over-projecting the thoracic column at height of carina.

Patient 1 is lean, patient 2 is normal sized and patient 3 is over-weight.

* See Table 2

** See Figure 3a and 3b

The 27 radiographers scored by assessing image quality, as a subjective choice. The most frequent choice of scores were the medium values for both sharpness and noise for all anatomical localizations in both projections, summed for all three body sizes. That is consistent with the fact that the images used for this study were already given acceptance, whereas they were used for reporting. The chosen images neither had any obvious pathology that could mask or make the RgQA be more difficult for the radiographers. A broader variation is the daily task for a radiographer, thereby they might score more differently, as also could illustrate a variation of a level for rejecting images. If radiographers are consistent with respect to rejecting images, is not too well studied yet. Likewise, it is also a lack of studies testing if radiographers are consistent with the reporters according image quality in digital radiography. Radiographers as a group revealed a more consistent preference than the radiologists with respect to image quality in a study using analogue urograms and finding there is a potential for image quality improvement by developing sets of image property criteria(Ween, 2005).

We found a high agreement within the majority of the 27 radiographers in the assessment of image quality, based on that among 30 evaluations, 28 was statistically significantly different from random distribution.

The lowest modal grade frequency, 13/27, is comparable to a random distribution with an average of 9/27. It must be noted that a high inter-observer agreement does not necessarily indicate that the level is correct. It must also be taken into consideration that the radiographers' evaluations were their first opportunity to use this particular rating scale; thereby, the scale might be more valid with increased experience. For instance, some of the radiographers questioned the reason why the non-superimposed vessels in the outer one third of the lung should be evaluated when planning the study. This is a direction to make them more aware of where and what to check for. Certainly, pathology will sometimes mask the vessels for evaluation. Even though, they showed a higher interest for the features of the digital image.

It may be questioned whether Kappa values for inter-observer agreement could be calculated, however, this is not feasible for other than dichotomy outcomes (Kraemer *et al*, 2002).

Subjective quality assessment

Observers do their image interpretation in relation to a “mental reference frame” as is what they perceive as normal versus abnormal. Acquiring perceptual expertise requires specialized training, experience, and to some degree, talent. Nodine *et al* (1993), doing perception research, opined that perceptual learning is typically absent in clinical practice (Nodine *et al*, 1993). Chest imaging is performed in a situation where a radiographer typically acts alone. In a study of the influence of perceptual and cognitive skills in mammography detection and interpretation, Nodine *et al* (1993) found that when the level of expertise decreased, false-positive results exerted a greater effect on overall decision accuracy over the time course of image perception (Nodine *et al*, 1993). In the beginning of digital radiography, it seemed being common to learn by example and by direct experience because there were real limits to the adequacy of verbal instruction. The proposed solution by our study is a systematic mentor-guided training that links image perception to feedback regarding the reasons underlying decision-making.

The choice of anatomical landmarks

By choosing plural anatomical landmarks for evaluation, there could be a possibility to evaluate sharpness and noise without pathological interference.

In this study, sharpness and noise evaluations varied between different anatomical landmarks. We propose that evaluation of more specified “technical-radiographic anatomical landmarks” would be helpful for the quality interpretation, in addition to the image quality criteria of digital chest radiographs described in the DIMOND III project (DIMOND, 2003). The structure types include lung structures such as vessels, soft tissue and bones; and all should be clearly seen in both projections, but preferably evaluated at different locations. Sharpness is best evaluated where the tiniest normal structures are shown (Vyborny, 2003), while noise is best evaluated where there is a high level of scatter. The amount of noise differs 7- to 10-fold between regions, even at optimal exposure (Håkansson *et al*, 2005).

The primary information is the only “true” signal that decreases due to anatomical noise, technical noise and quantum noise. The anatomical noise depends on positioning and the extent of air inspiration.

Similarly, the technical noise (the texture) is caused by exposure techniques as e.g. the choice of focus size, and the quantum noise depends on pixel size and detector characteristics. The summed amount of noise would be most prominent in the over-weight patient (patient 3) due to a larger object thickness. The results of our study also shows that the impression of noise does not differ considerably in the lower anatomical landmarks rated in the patient 3 as compared to the others. This can be due to the fact that image quality is obtained homogeneously using an automatic exposure control (AEC) thus different body sizes are compensated for.

If the exposure is made before the patient have reached maximal inspiration, the central ray is directed too low, or the AEC settings are not chosen according to the body thickness, the exposure time will be prolonged. This will in turn lead to unsharpness because of body, organ and/ or tissue movement; and also to increase the noise because of the higher amount of scatter from the upper abdomen.

The threshold visibility is not only influenced by the border of the lesion shadow (the angle of which a lesions surface is met), but also by its location. The visibility is higher when a lesion is superimposing parenchyma alone than other organs in the chest. Typical “blind” areas are the retro-cardiac area, hila, para-mediastinal areas, locations superimposed by skeletal structures, and areas below the diaphragm. The anatomical areas chosen for this study consisted both of optimal areas (peripheral lung parenchyma), and also of one example of a “blind” area; the retro-cardiac. Radiographers should probably emphasize more on quality evaluation of known blind areas.

Movement, sharpness and noise

The challenge is to identify low-contrast septum lines targets, or pulmonary nodule targets (Vyborny,1997) towards a complex background. Patient movement, tissue (organ or structure) movement, or equipment movement are the important sources of sharpness deterioration. In practice, motion artefact is a limiting factor (MacMahon , 2003). The most important nodules are small (Fink *et al*,2002) and will become invisible if sharpness is low. It is well known that the superposition of noise can induce some blurring effect: edges become less sharp (van Ongeval, 2008). A noisy but sharp image is usually preferable compared to a smooth but blurred one. A moderate level of noise that appears firstly in under-penetrated areas, such as the mediastinum, is of no diagnostic consequence, and should be accepted as an evidence of appropriate exposure. In our study, with respect to the diaphragm and heart contours, the retro-cardiac area is surprisingly given only a few scores for both poor sharpness and high noise grades in case of patient number 3. This was unexpected, as patient 3 was large-sized, leading to a longer exposure time. However, if the AEC's is positioned over the air-filled lung fields, the exposure time should be short. A radiographer should balance geometric versus movement unsharpness.

The importance of processing

We did not record panellists' use of image processing tools, such as windowing, pan or zoom functions, or differing in viewing distances. In a study of mammography by Krupinski *et al* (2005), it was found that experienced readers tend to use windowing more often, while inexperienced used magnification more often. They suggested that experienced observers are more able to judge the relevant characteristics of lesions. While doing clinical interpretation of mammograms they normally used windowing, as thus probably they had a better understanding of what they were looking for and how changes in windowing could affect the appearance of the structures they were looking at. Variations in the usage of windowing might be a bias in the evaluation of sharpness in our study, as this is based on impression of evaluation of anatomical structures.

In Taplin's mammography study, magnification was used to a varying degree in the evaluation of sharpness versus noise (Taplin, 2002). Magnification and distance variation are described as valuable tools for visualization of point structures as micro-calcifications and fine-detail hand radiographs (Vyborny, 2003). In chest images, isolated point targets (<1 mm) are usually not of diagnostic importance neither for sharpness nor noise, except for pneumoconiosis; as was excluded from this study.

The limitations of the study

We used only three patients' images. They might neither be representative of the variation in body habit nor of the exposure techniques. The images were already seen as '*good enough for diagnostic use*' and homogenises the imaging material. Thus, agreement would be better if the images that occur in daily practice were included. Images with pathology were not included in this study to avoid too many variables, but should be included in further studies. The lack of obese

patients might have influenced the agreement. Images having a larger variation with respect to structures types seen, movement, target geometry and signal-to-noise ratio would probably give a higher discriminatory effect.

Efforts were made to create the quality criteria as few, clear and unambiguous as possible. For instance, an evaluation of a defined area like the middle of the heart contour rather than the whole length of the heart contour was done to avoid the possible problem that only some structures might be sharply reproduced.

A way forward

Lung cancer is the leading type of cancer (Fitzmaurice and Dicker, 2015). Plain chest radiograph screening has been shown to be ineffective as a screening model for lung cancer (Deffebach and Humphrey, 2015); even though, chest radiography still is the primary imaging method for patients who have suspected chest disease and the imaging tool of choice for the assessment of complications and during follow-up of patients who have pulmonary diseases (Howarth and Tack, 2011). Plain chest radiography has a large potential, when it is performed with accuracy, combined with a specific technique for double deep inspiration breath-hold, and a mentor-based gradual scaled quality assessment method.

Conclusion

Chest radiography still remains one of the most challenging diagnostic tools, considered as “the gold standard”. Due to the wide range of possible diseases, still it is important despite new powerful imaging techniques such as high-resolution computed tomography, dual energy CT and CAD.

Radiographers should turn every stone to help better accuracy. This study presents a method for subjective assessment of noise and sharpness, in a clinical setting. The results showed a high inter-observer agreement. This was the radiographers’ first attempt to use this particular rating scale; therefore, the method might be more consistent with increased experience. We propose that the method investigated, should be tested using a systematic mentor- based learning, combined with precisely positioning and an improved technique for maximal inspiration breath-hold. This may increase consistence in image perceptions and improve the basis for image retake decisions and quality improvement.

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